

# PATENT SPECIFICATION

1,062,593

DRAWINGS ATTACHED.

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## COMPLETE SPECIFICATION.

### Improvements relating to Electrolytic Machining.

We, ASSOCIATED ELECTRICAL INDUSTRIES LIMITED, a British Company having its registered office at, 33 Grosvenor Place, London, S.W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

It is well-known that a workpiece can be given the inverse shape of a tool by forming an electrode gap between them, whose size is small, 0.005 in. for instance, in an electrolyte, the tool forming the cathode and the workpiece the anode of a direct-current circuit. The current passing through the gap is normally much larger than that used in electroplating processes and a rapid flow of electrolyte through the electrode gap is normally maintained. Under these conditions material removed from the workpiece does not adhere to the tool and the workpiece gradually assumes a shape similar to the tool.

A known method of electrolytic machining maintains constant the electrode gap by automatically regulating a drive advancing one of the electrodes forming the gap. This known control operates with regulating the electrode feed rate in dependence upon the pressure of the electrolyte which is forced through the electrode gap.

The present invention aims at a higher degree of accuracy than obtainable heretofore. This is achieved by maintaining constant a mass-flow rate of the electrolyte selected in accordance with the actual machining work.

Accordingly the present invention resides in a method of electrolytic machining comprising forcing an electrolyte flow through a restricting electrode gap between end faces

of a tool and a workpiece connected respectively to opposite poles of a direct current source, applying a substantially constant bias force which tends to reduce the electrode gap size, while maintaining constant the mass flow rate of the electrolyte to suit an actual machining operation.

As the mass flow of electrolyte is rigidly maintained constant, not subjected to changes due to the control of any part of the machining apparatus, and is set to suit the machining of an actual workpiece component, greater fidelity of the shape machined to the shape desired can be achieved than has been possible up to now.

The invention also relates to apparatus for carrying out the said method.

In order that the invention may be more readily understood reference will now be made to the drawings accompanying the Provisional Specification, in which:

Fig. 1 is a side view partly in section of apparatus for the electrolytic machining of a metal embodying the control methods of the invention, and

Fig. 2 is a side view partly in section of another type of apparatus.

Reference will also be made to the accompanying drawing, in which:

Fig. 3 is a diagrammatic side view of yet another type of apparatus, and

Fig. 4 is a side view in section of one component of the apparatus illustrated in Fig. 3.

With reference to Fig. 1 the apparatus comprises a fixed support 1 of electrically conducting material for a component 2 being machined and a cylinder 3 mounted upon the support 1, together with a piston 4 of electrically conducting material free to move within the cylinder. The piston supports a

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tool 5 at its lower end and a duct 6 connects with the lower end of the cylinder below the piston. The piston is hollow and a second flexible duct 7 connects with the hollow centre of the piston. A third duct 8 connects with the upper end of the cylinder. Electrical leads 9, 11, are attached respectively to support 1 and to piston 4, lead 11 being flexible. The cylinder 3 is conveniently of electrically insulating material and the piston 4 is sealed within the cylinder by suitable sealing rings 12. The lower end of the cylinder is adapted to be sealed to the upper surface of the component 2 by a suitable sealing ring 13.

The tool 5 is a hollow drill of any desired cross-sectioned shape and is formed from a tube 14 of brass or stainless steel covered with a layer 15 of electrically insulating material. Only the lower annular end face 16 of the external surfaces of the tube is exposed to the electrolyte which is supplied through duct 6 and flows through the drill 5 and the hollow piston 4 and flows out through duct 7. The electrolyte flow is provided by a pump 17 which is arranged to maintain the mass flow rate of electrolyte substantially constant, regardless of the pressure of electrolyte within the cylinder.

A hydraulic fluid such as oil is supplied to the cylinder 3 through duct 8 from a suitable pump 19 at a variable pressure. In an alternative arrangement the piston is connected to a spring mechanism providing the biasing force.

Leads 9, 11 are connected to a source of potential 21 so that the support 1 is maintained at a positive potential relative to the tool 5.

An arm 22 is attached to piston 4 and abuts against the moving rod of a dial indicator 23 so as to indicate any vertical movement of the piston.

In order to machine the upper surface of the component 2 with the drill 5, the electrolyte is caused to flow through the lower part of the cylinder 3, and the lower end of the tool 5 is moved into proximity with the surface of the component by increasing the pressure of the oil in the upper part of the cylinder and overcoming the force exerted on the piston by the electrolyte under pressure in the gap between the tool and the component. The gap between the tool and the component is reduced to about 0.005" and a reading of the dial instrument 23 is taken.

When the desired size of gap has been attained an electrical potential is provided between the tool and the component so that erosion of the surface of the component takes place in the well known manner. As metal is removed from the component the restriction offered to the flow of the electrolyte in the gap between the tool and the com-

ponent is reduced and the pressure of the electrolyte drops. The pressure of the oil is maintained constant so that the piston 4 moves downwards so as to reduce the size of the gap. This increases the pressure of the electrolyte and the piston moves downwards until the original size of gap is re-established and the forces on the tool from the oil and the electrolyte are equal.

The material of the component continues to be eroded away while the gap between the tool and the component is maintained at the constant predetermined value. The machining process can therefore be arranged to take place under the most efficient conditions, and the rate of machining may be varied, by varying the current between the tool and the component, without altering the size of the gap between the tool and the component.

If it is desired to machine right through the thickness of the component, an electrically insulating resilient pad 24 is placed between the support 1 and the surface of the component opposite the tool 5 so that when the tool machines through the component it makes contact with the pad 24. When this occurs the machining process ceases and the pad seals the electrolyte within the cylinder.

The movement of the tool towards or into the surface of the component is indicated by the indicator 23.

Fig. 2 illustrates an alternative apparatus for machining both sides of the component simultaneously, for example for machining both sides of a turbine blade. The apparatus comprises a support 31 for a component 32 within a cylinder 33 together with two pistons 34, 35 free to move in the cylinder and adapted to hold tool 36, 37 respectively. These tools are used to machine the opposite sides of the component. The electrolyte is supplied to the middle part of the cylinder 33 and has a substantially constant mass flow, entering along a duct 38 and exhausting along another duct 39. Oil is supplied to the two ends of the cylinder along ducts 41, 42 from a pump 43 at a variable pressure.

A mechanical linkage 44 links the two pistons 34, 35 so that they move equally in opposite directions. Leads 45, 46 are provided for connecting the piston and the component relatively to suitable sources of electrical potential. Leads 45 are flexible.

In a modified form of this second apparatus the pistons 34, 35 are moved by connecting rods connected to two more pistons located in cylinders remote from cylinder 33, and the linkage between pistons 34, 35 is hydraulic. Also the movement of the pistons 34, 35 may alternatively be controlled by a spring.

This second type of apparatus operates in a manner similar to the apparatus described

above with reference to Fig. 1. Electrolyte is caused to flow through the cylinder 33 at a constant rate of mass flow and the pressure of the oil is increased until the surfaces of the tools 36, 37 are spaced from the adjacent surfaces of the component 32 by a small gap. A potential is then applied between the component and the tools so that the component becomes positive with respect to the tools and erosion of the surface of the component takes place in the well known manner. Each component wears away and as the gap between the component and the tools tends to increase in size the pressure of the electrolyte tends to decrease. As described above, this causes the pistons together with the tools to move towards the component so as to maintain each gap at a constant value.

The two types of apparatus described above incorporate the principle of using the pressure of the electrolyte to control the movement of the tool so as to keep the gap between the tool and the component of a constant size. The size of the gap is preset before the machining process is commenced by adjusting the size of the force on the tool. This force is maintained constant throughout the machining process.

The method of controlling the movement of the tool operates completely independently of the electric parameters of the apparatus and is therefore very flexible in its application.

The insulating coating 15 (Fig. 1) is preferable, tough and resistant to chemical and electrical attack, and is of the order of 0.002 inches thick. The diameter of the hole drilled is larger than that of the tool. With a gap of between 0.003 and 0.005 inches between the surfaces of the tool and the component, an average of 0.05 inches on the diameter of the hole machined is typical on holes more than 0.25 inches in diameter when the electrolyte flow is radially inwards across the end face of the drill. When the flow is radially outwards, as described in the subsequent improved apparatus in Fig. 3, the predictable amount of oversize can be much reduced, say to 0.010 inches on diameter. This over sized drilled hole leaves a gap for the passage of the electrolyte. The added restriction to the flow of electrolyte as the drill penetrates further causes a slight increase in gap size but this is not appreciable in the arrangements described.

The electrolyte may be a sodium chloride solution. Any metal conductor can be used for the master tool but a corrosion-resisting metal such as an austenitic steel is needed for long life. Brass could be used for ease of machining and mild steel for economy where only a few components are to be machined.

In an alternative form of the apparatus described above a signal of a change in pressure in the gap could be supplied from an auxiliary flow of electrolyte, independent of the main flow, and pumped through the tool at a selected point.

Fig. 3 illustrates diagrammatically an improved apparatus for electrolytic machining comprising a control system which embodies the method the invention and including a servo mechanism to improve the accuracy and sensitivity of the control.

The apparatus comprises a tray 51 in which is supported a workpiece 52 to be machined, and a tool 53 mounted in a holder 54 supported on a rod 55 the vertical position of which is controlled by a cylinder 56. The tool 53 is hollow and a pipe 57 adapted to carry electrolyte is connected to the hollow inside of the tool. The lower end 58 of tool 53 is adapted to be located adjacent to the surface of the workpiece 52 so that electrolyte can flow through the tool, through the gap between the end 58 of the tool and the surface of the workpiece, and out into the tray 51. A D.C. power supply unit 59 is provided. The positive terminal of this power supply unit is connected to the workpiece 52 by a suitable contact 61 and the negative terminal is connected to the tool 53 by another suitable contact 62.

Electrolyte is supplied to the tool 53 from a reservoir 63 by a pump 64 and passes through a filter 65, an orifice valve 66 and a flexible pipe 67 connecting with the pipe 57. The electrolyte flows at a substantially constant mass flow rate and is returned to reservoir 63 from the tray 51 through a pipe 68. An accumulator 69 may be provided between the pump 64 and the filter 65 to ensure smooth delivery of the electrolyte.

A variable relief valve 71 or similar control device is connected between the output end of the filter 65 and the reservoir 63 so as to vary the output pressure P1 of the electrolyte on leaving the filter. This pressure is indicated on a gauge 72. The pressure P2 of the electrolyte on leaving the orifice valve 66 is indicated on a gauge 73.

The orifice valve 66 comprises a sharp edged orifice through which the electrolyte flows and can be changed depending on the control requirements of the apparatus. A pipe 74 connects the output end of the valve 66 with a servo control valve 75 which is described in detail below with reference to Fig. 4.

The electrolyte supply system described above provides a constant flow of electrolyte at a predetermined mass flow rate through the tool 53 and the gap between the tool and the work piece so that electrolytic machining of the workpiece will take place when the D.C. supply unit 59 is connected between



the tool and the workpiece, as illustrated.

The position of the tool 53 is controlled by a hydraulic system operating on cylinder 56. Hydraulic fluid for example oil is supplied from a constant pressure source at a pressure P3 indicated by a gauge 82 and passes through a pipe 83 to the upper chamber of cylinder 56. A piston 84 is mounted on rod 55 and is located within the cylinder 56. The upper surface of the piston closes the bottom end of the upper chamber of the cylinder and its effective area is reduced by an extension rod 86 extending through the end of the cylinder. The lower surface of the piston closes the upper end of the lower chamber of cylinder 56 and its effective area is approximately equal to twice the effective area of the upper surface of the piston. The rod 55 will therefore normally be stationary relative to cylinder 56 if the pressure in the upper chamber is twice the pressure in the lower chamber. This pressure ratio must be adjusted to account for static friction of the seals, bearings etc., the weight of components and the pressure of the electrolyte exerted on the tool 53.

Hydraulic fluid from pipe 83 is passed along a pipe 87 through a variable restriction 88 into the lower chamber of cylinder 56. The resultant pressure exerted on the lower surface of piston 84 is indicated by a gauge 89. The position of the rod 55 can be varied by varying the ratio of the pressures exerted on the two surfaces of piston 85. Rod 55 is supported in a bearing 91 as it emerges from the cylinder and directly controls the position of the holder 54 and the position of the tool 53.

The output from the variable restriction 88 is also supplied along a pipe 92 to the servo control valve 75 and the servo valve allows a selected amount of hydraulic fluid to return to the supply 81 and thereby produces a pressure drop across the restriction 88. The value of this pressure drop depends on the setting of the restriction 88 and on the amount of hydraulic fluid flowing through the servo valve 75.

The servo valve 75 is supplied with electrolyte at pressure P2 and with hydraulic fluid at pressure P4. After the initial setting up, the value of P2 depends on the size of the gap between the tool 53 and the workpiece 52 and if this gap increases the value of P2 will drop. By the operation of the servo valve 75 this pressure drop will cause a corresponding drop in the value of P4 and will cause the rod 55 to move downwards thereby reducing the gap between the tool and the workpiece and consequently increasing the value of P2. Hence the servo control system enhances the effect of the constant flow rate control of the pump motor whereby to ensure that the gap between the tool and the workpiece is maintained at a

constant predetermined value, thus resulting in accurate machining of the workpiece as described above. The use of the servo valve 75 ensures that small changes in the value of P2 are amplified and therefore improves the sensitivity of the apparatus.

The servo valve 75 is illustrated in greater detail in Fig. 4 which is a side view of the valve sectioned on an axial plane. The servo valve comprises two chambers 101 and 102 separated by a flexible neoprene diaphragm 103. Electrolyte at pressure P2 is supplied into the lower chamber 102 along pipe 74 and hydraulic fluid at pressure P4 is supplied through the upper chamber 101 along pipe 92 and drains from the upper chamber by gravity to the source 81. A control disc 104 is located adjacent the lower end of pipe 92 and is supported from the body of the valve on a spring 105 which abuts against the upper flanged end 106 of a cylindrical component extending vertically from and secured to the disc 104.

The pipe 92 is fixed to the body 100 of the servo valve and is formed with a threaded portion 107 on its outer surface. A hand-wheel 108 engages on this threaded portion and the lower end of hand wheel 108 projects in a fluid tight manner into chamber 101 and abuts against a collar 109. This collar extends around the pipe 92 and is connected to the outer surface thereby so as to be free to slide longitudinally over this surface. A second spring 110 extends between collar 109 and disc 104.

Forces are exerted on the disc 104 by the pressure P2 in the chamber 102 acting through the neoprene diaphragm 103 and by the springs 105, 110. The value of pressure P4 depends on the rate of flow of the hydraulic fluid from pipe 92 through chamber 101 to the source 81, and this value is controlled by the size of the gap between the lower end of pipe 92 and the upper surface of disc 104.

The downward forces exerted on disc 104 by spring 110 can be varied by adjusting the position of the hand wheel 108. When the hand wheel is screwed fully out of the chamber 101 no downward force is exerted on disc 104 by spring 110 and disc 104 is forced against the end of pipe 92 and fully interrupts the flow of hydraulic fluid even when the value of P4 is a maximum. Hence the value of P4 under these conditions is high. As the hand wheel 108 is screwed further into chamber 101 the force exerted by spring 110 increases and the disc 104 eventually moves away from the end of pipe 92 so as to permit the flow of hydraulic fluid through the chamber 101 and cause a corresponding reduction in the value of P4.

The reduction in the value of P4 will reduce the upward force on piston 84 and will cause downward movement of rod 55. This

will cause a decrease in the gap between the tool and the workpiece and an increase in the value of P2. This pressure increase causes an upward movement of disc 104 and a reduction in the flow of hydraulic fluid and a consequent increase in P4 which eventually halts the movement of rod 55. Further inward movement of the hand wheel 108 will adjust the equilibrium size of the gap between the tool and the workpiece and the control system will operate subsequently to maintain the size of this gap constant.

As the machining operation takes place in the gap between the tool and the workpiece tends to increase thereby providing a reduction in the value of P2. This results in a downward movement of disc 104 and a reduction in the pressure of P4 causing a downward movement of rod 55. The consequent reduction of the gap between the tool of the workpiece increases P2 again until equilibrium conditions are once more attained with the gap having its original size.

The modified apparatus illustrated in Figs. 3 and 4 has been described in use with a single tool 53. It will however be appreciated that it could alternatively be used to control the movement of two or more tools, as for example in the arrangement illustrated in Fig. 2.

#### WHAT WE CLAIM IS:—

1. A method of electrolyte machining comprising forcing an electrolyte flow through a restricting electrode gap between end faces of a tool and a workpiece connected respectively to opposite poles of a direct current source, applying a substantially constant bias force which tends to reduce the electrode gap size, while maintaining constant the mass flow rate of the electrolyte to suit an actual machining operation.

2. A method as claimed in claim 1 wherein the electrolyte flow is separated throughout from the surrounding atmosphere.

3. Apparatus for carrying out the method claimed in claim 1 comprising means for supporting the workpiece component to be machined, means for supporting a tool adjacent to the surface of said component, means for connecting said component and

said tool respectively to suitable sources of electrical potential, means for causing electrolyte to flow through the gap between the component and the tool at a constant mass flow rate, and means for exerting biasing force which is substantially constant and tends to move said component and said tool relatively towards each other.

4. Apparatus as claimed in claim 3 in which said tool is mounted on a piston in a cylinder to which pressure fluid is supplied.

5. Apparatus as claimed in claim 4 in which hydraulic pressures are exerted on both sides of the piston one of said pressures being constant and the other having a controlled variable value.

6. Apparatus as claimed in claim 5 comprising a servo valve which correlates the controlled pressure applied to the piston with the electrolyte pressure.

7. A method of electrolytic machining substantially as described with reference to the accompanying drawings and the drawings accompanying the Provisional Specification.

8. Apparatus for electrolytic machining by the method claimed in claim 1 substantially as described with reference to Fig. 1 of the drawings accompanying the Provisional Specification.

9. Apparatus for electrolytic machining by the method claimed in claim 1 substantially as described with reference to Fig. 2 of the drawings accompanying the Provisional Specification.

10. Apparatus for electrolytic machining by the method claimed in claim 1 substantially as described with reference to Fig. 3 of the accompanying drawings.

11. Apparatus for electrolytic machining by the method claimed in claim 1 substantially as described with reference to Figs. 3 and 4 of the accompanying drawings.

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Fig 3

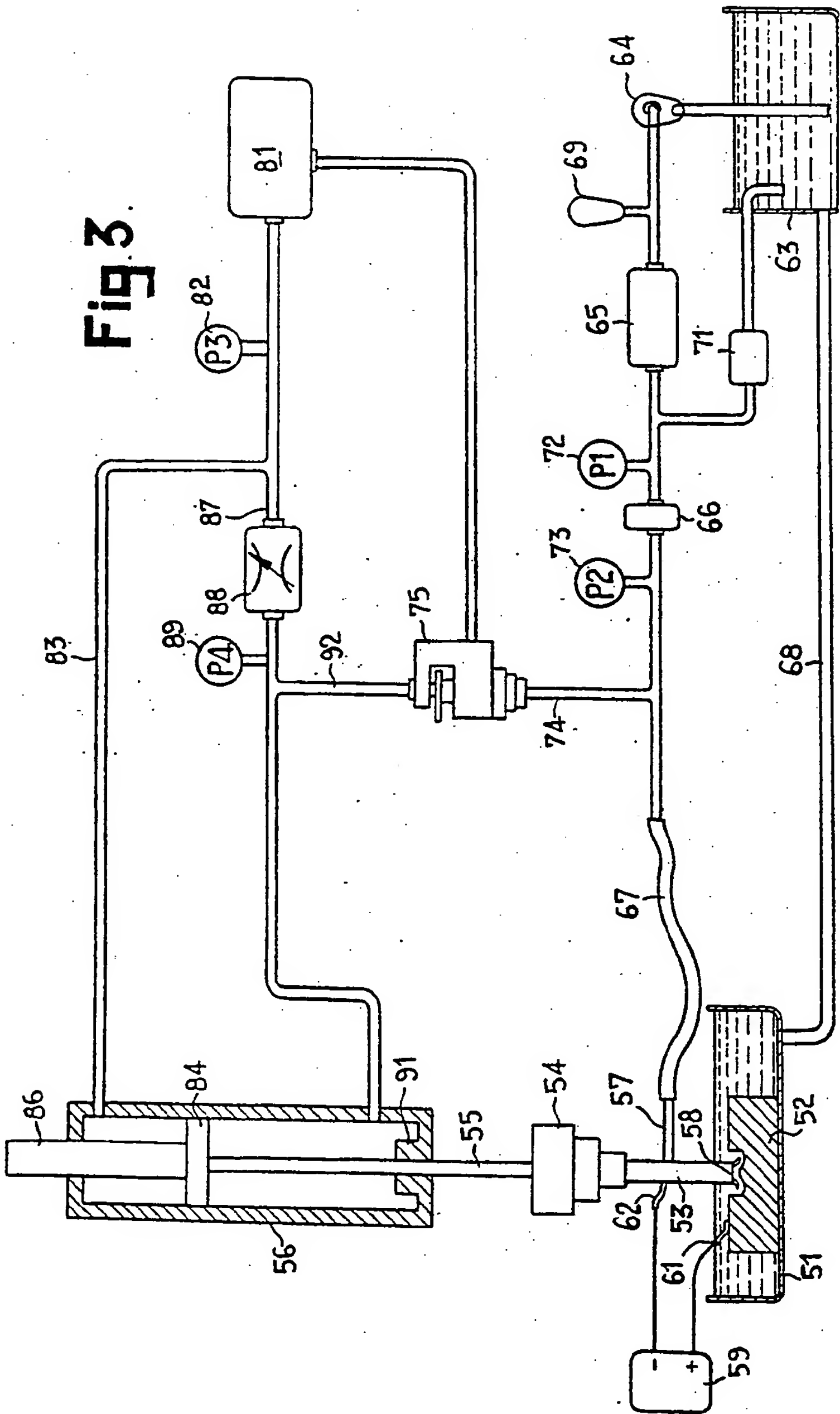
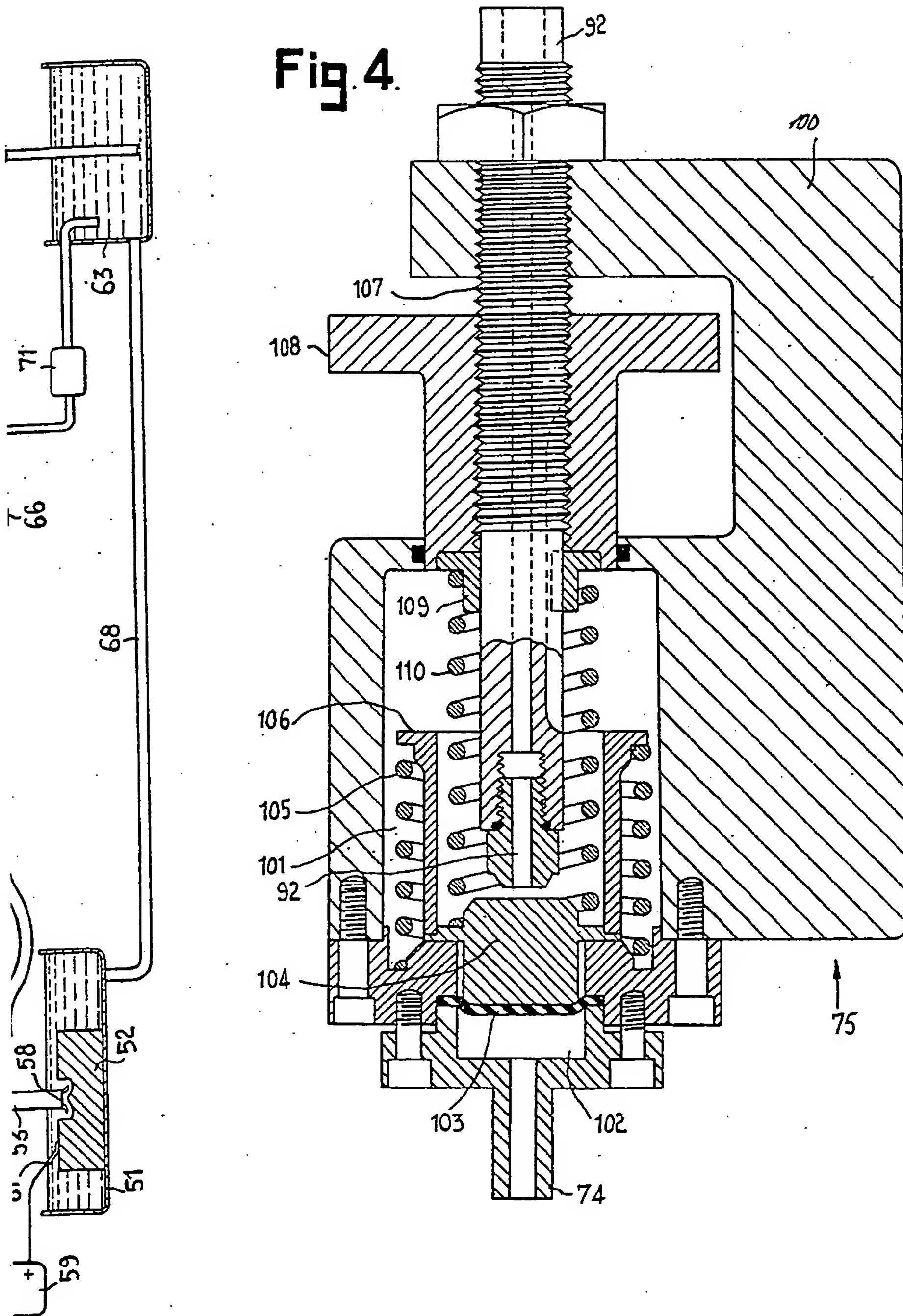
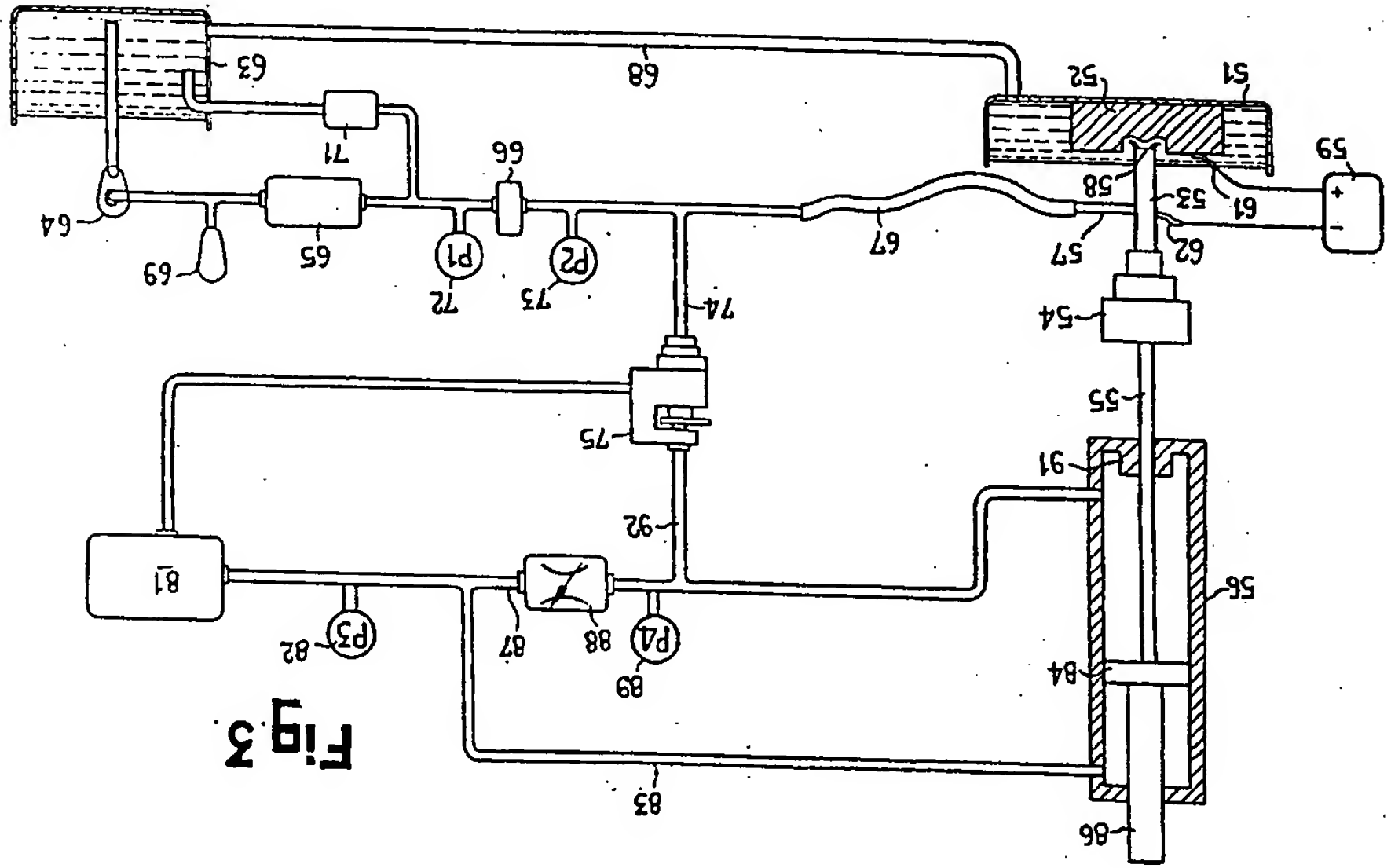
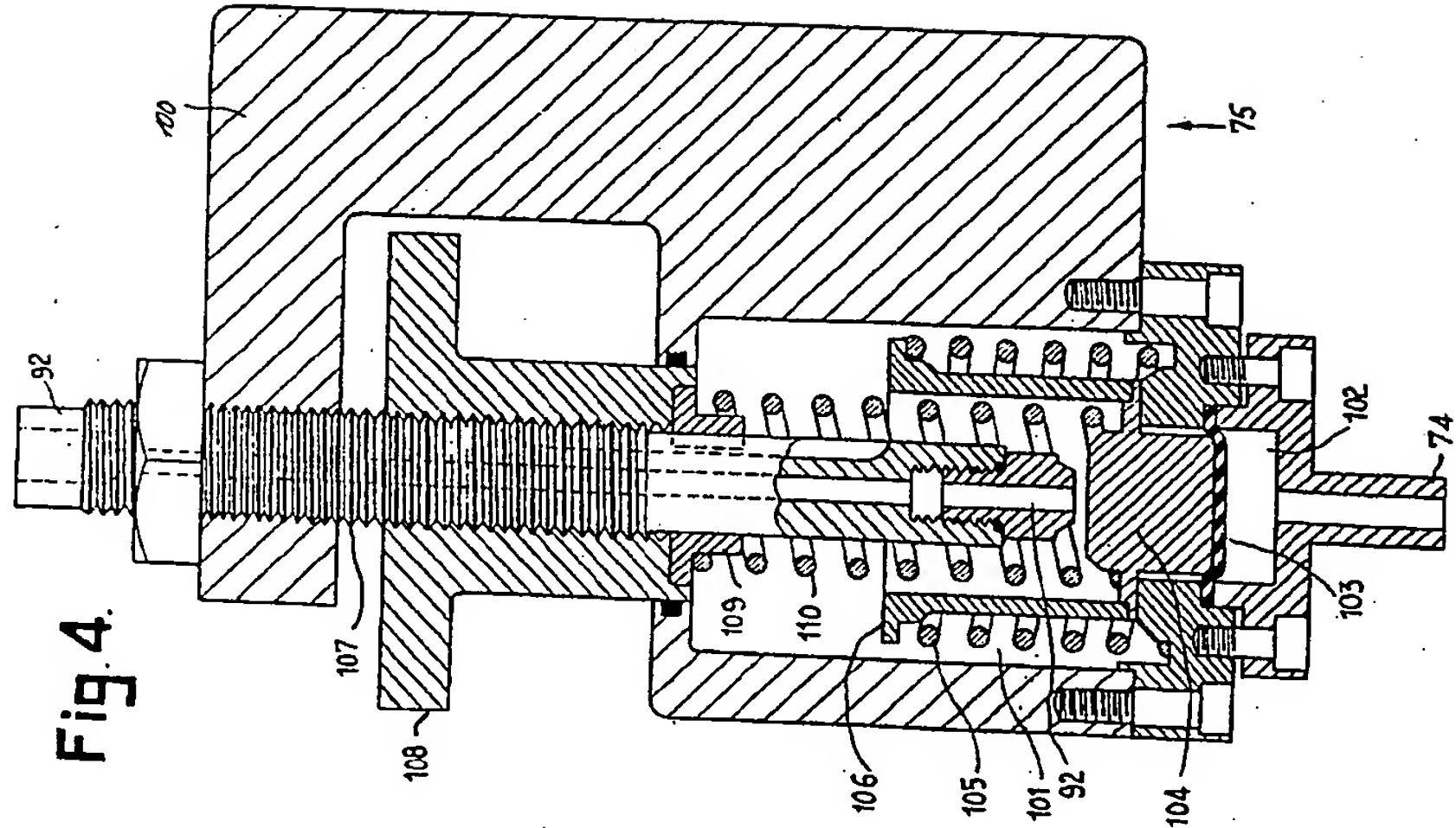


Fig. 4.







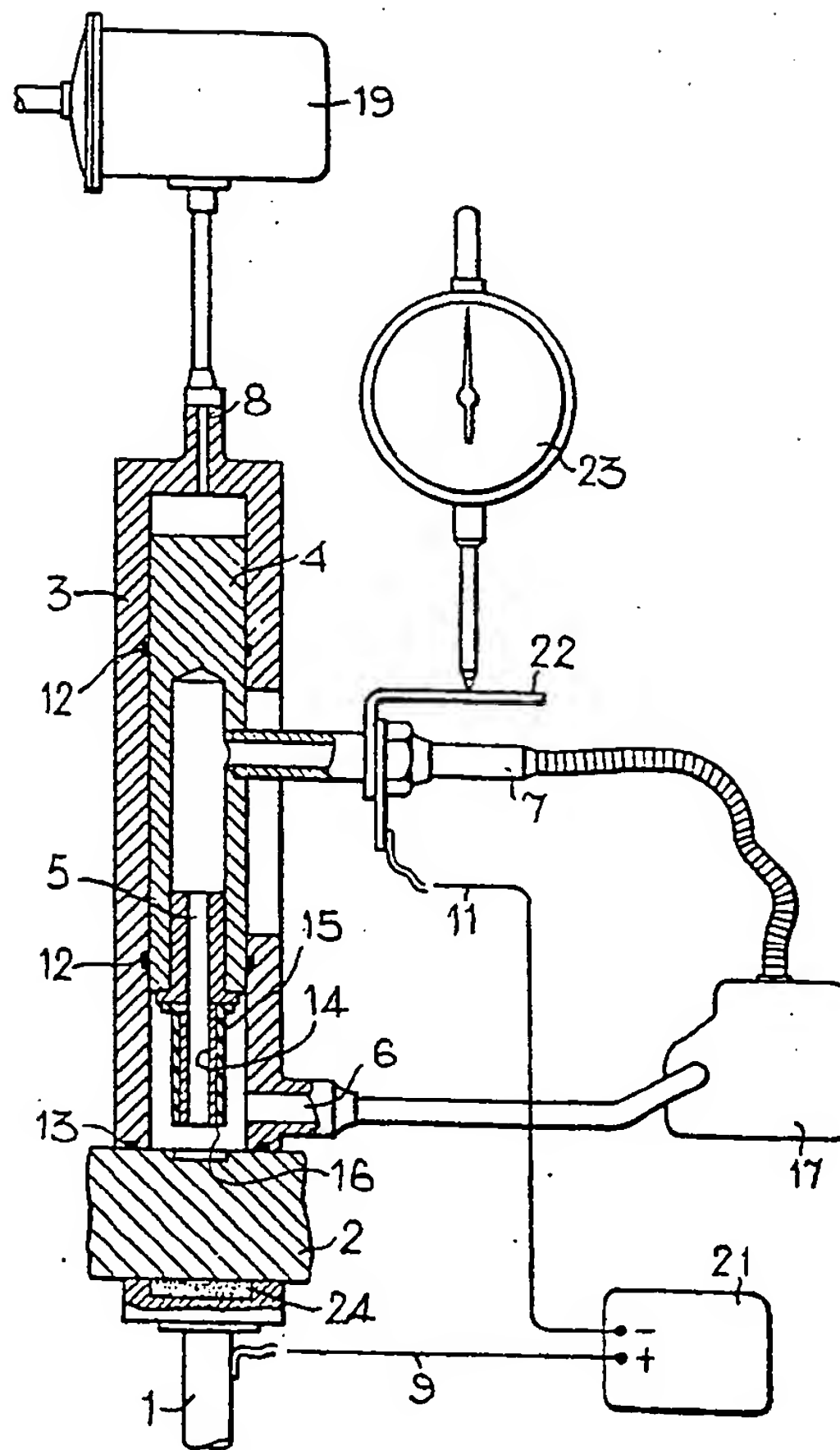


Fig. 1.

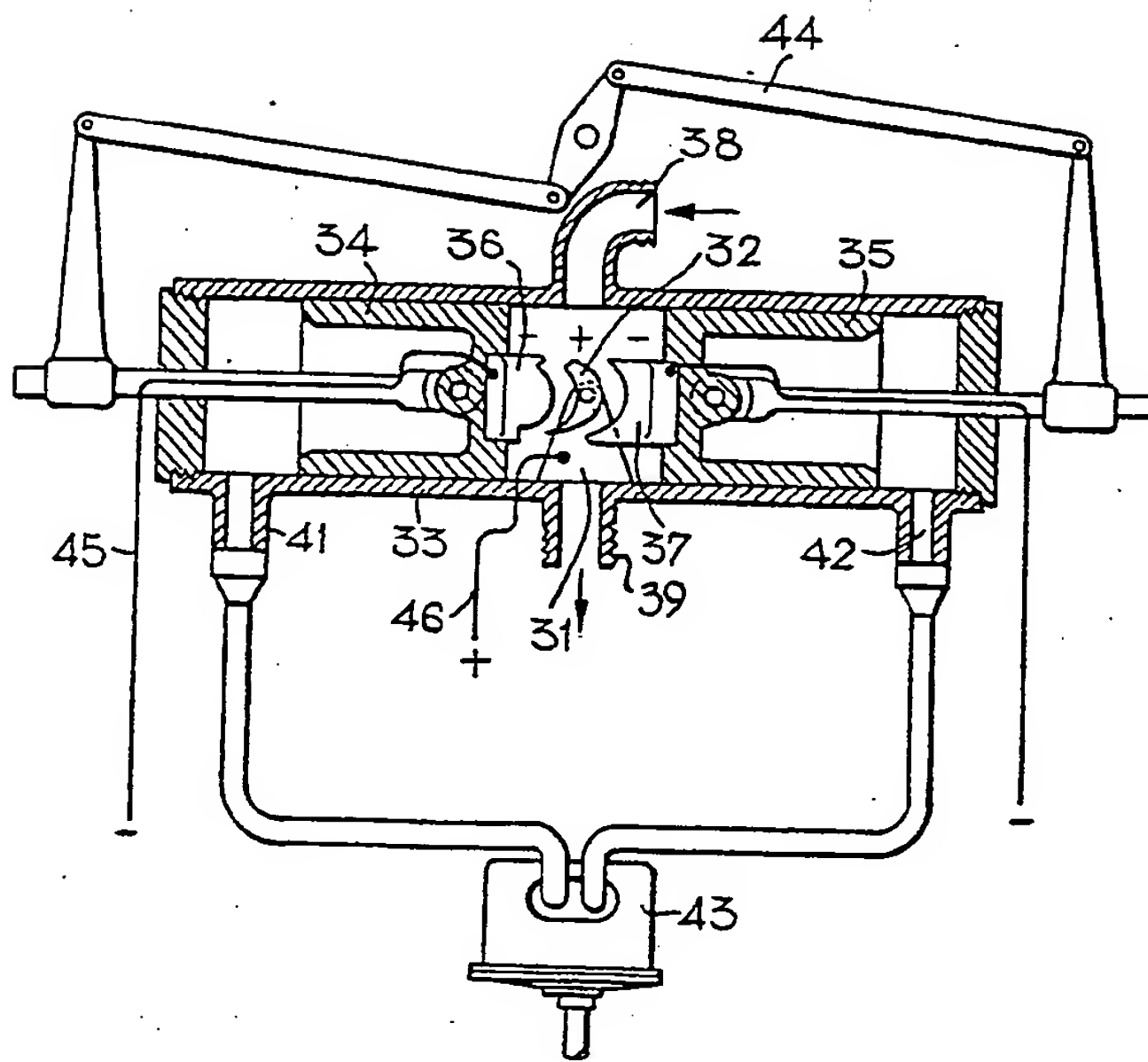


Fig. 2.

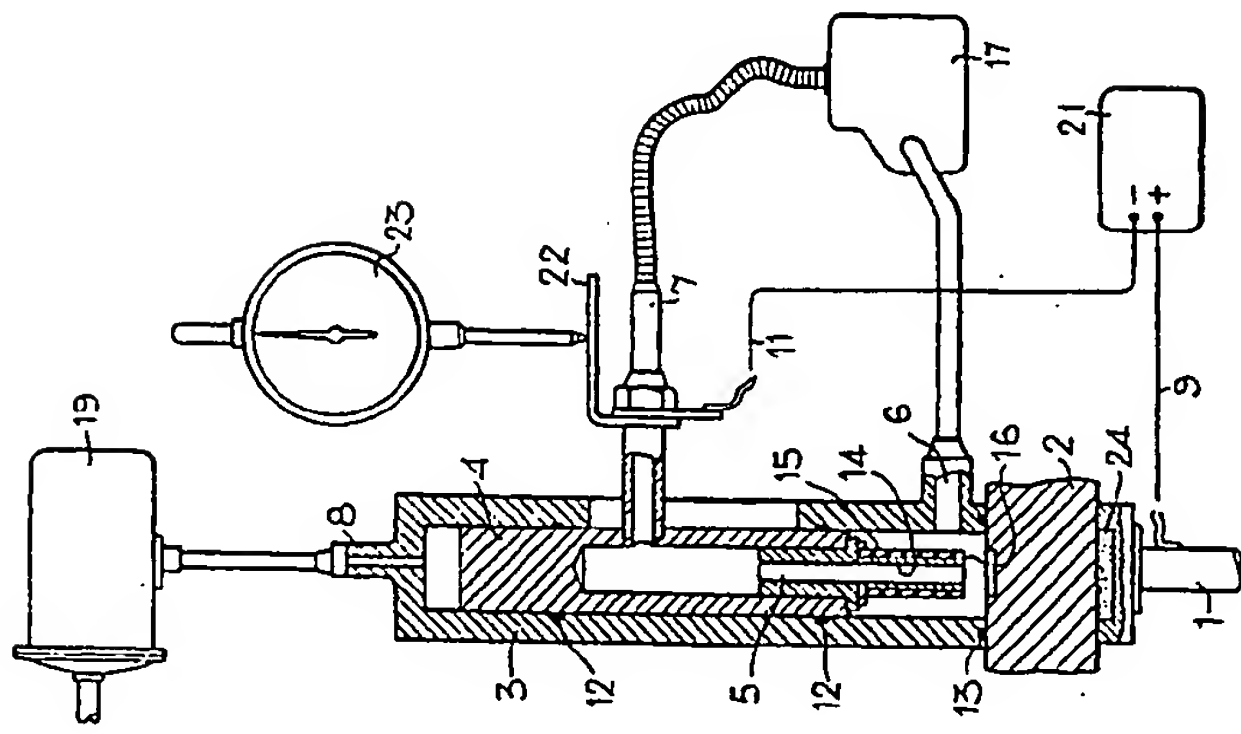


Fig. 1.

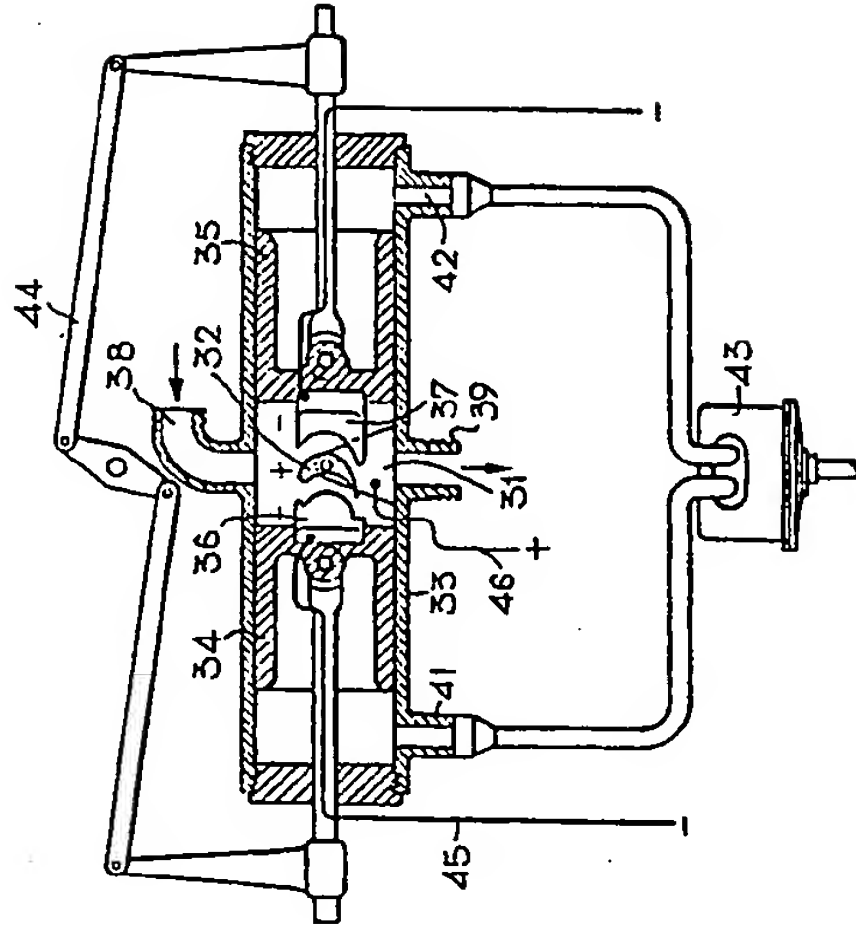


Fig. 2.

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